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CHARM RESULTS ON CP VIOLATION AND MIXING

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ABSTRACT

The most recent results on CP violation and mixing in the charm system are reviewed as a guide to the future. While no surprising results are reported so far, charm provides a unique window to physics beyond the Standard Model. The results reported here come from four sources: ALEPH at LEP, E791 and FOCUS/E831 at Fermilab, and CLEO II.V at CESR. Results beyond these sources may be expected as a byproduct of B-motivated experiments.

1 Introduction

So far, there is no evidence for either CP violation or particle-antiparticle mixing in the charm-quark sector. This is as expected in the context of the Standard Model of particle physics. Predictions for CP violation and particle-antiparticle mixing are orders of magnitude below the sensitivities of current

experiments. This remains true even though today's experiments are part of the march toward Standard-Model sensitivities, a march which has seen a couple of orders of magnitude increase in sensitivity in each of the last two decades.

1.1 The Present as a Guide to the Future

What would be really exciting is the observation of CP violation or particle-antiparticle mixing in current charm experiments. The Standard-Model predictions which explain these effects for strange and bottom quarks typically predict (so far) unmeasurable effects for charm. In that case, experimental charm signatures have no Standard-Model background, no relevant hadronic uncertainty in background estimates. Any sighting of CP violation or mixing in the charm sector would be evidence of new physics. Since no such sighting has been made, we must settle, for now, simply to use the current experimental efforts as guides to future possibilities. How can we best pursue the search for CP violation and particle-antiparticle mixing?

Today's results come from four sources of charm particles: e^+e^- experiments in the upsilon region (CLEO II.V at CESR) and at the Z^0 (ALEPH at LEP), photoproduction (FOCUS/E831 at Fermilab), and hadroproduction (E791 at Fermilab). From the next generation of experiments, we may hope for a continuation of increased sensitivity - though in a more limited set of experimental environments.

1.2 Charm, a Unique Window to New Physics

While the charm-physics sector has no measurable Standard Model mixing or CP violation, it is unique in much more interesting ways than simply having no Standard-Model backgrounds. It is the only opportunity to see new-physics coupling to the up-type-quark sector. In the case of the up quarks themselves, there is a lack of sufficient particle lifetime and richness in decay channels for CP violation or particle-antiparticle mixing to be manifest. As for the top quark, it doesn't live long enough to be included in particles which can mix or can have the final state interactions needed to see CP violation.

The smallness of the Standard-Model diagrams gives insight into the uniqueness of the charm sector. Possible contributions from box, penguin, and long distance effects are usually all about same order.¹⁾ Even when long distance effects are thought to be larger than perturbative Standard-Model ef-

fects, the predictions are still many orders of magnitude from present limits.²⁾ Any of a long list of non-Standard-Model sources could produce measurable mixing or CP violation in charm.^{3) 4) 5) 6)} These include leptoquarks, SUSY particles, fourth-generation quarks, left-right symmetric particles, and Higgs particles.

2 Particle-Antiparticle Mixing

Particle-antiparticle mixing can occur only for neutral particles, such as the D^0 . Three types of measurements have been made: those using hadronic decays, those using semileptonic decays, and those where comparisons are made in the decay rates to various mixtures of CP eigenstates. In the first two of these, one needs to know the nature of the D meson when it is born, i.e., produced. Such mesons are referred to as tagged (as to particle-antiparticle nature at birth). We also need the nature of the particle at the time of its decay, typically given by one or more of the decay particles. In the case of lifetime comparisons, one may use untagged mesons, and gain the increase in efficiency implied.

Universally, tagging of D^0 's is done by examining only those D^0 's which are the decay products of charged $D^{*'}s$. In this case, the strong decay of the $D^{*\pm} \rightarrow D^0\pi^\pm$ gives the nature of the charm quark in the D^0 , since it is the same as that in the D^* , and is marked by the D^* charge and that of the daughter charged pion. Clearly, using only such D^0 's reduces the size of the D^0 -sample available for study. Fortunately, the production of $D^{*'}s$ is frequent in charm events, and the $D^0\pi^\pm$ decay is both copious and easy to observe.

To date, the observed decays used in mixing studies are:

Hadronic Decays: $D_{tag}^0 \rightarrow K\pi$ and $\rightarrow K\pi\pi\pi$

Semileptonic Decays: $D_{tag}^0 \rightarrow K\mu\nu$ and $\rightarrow Ke\nu$

Lifetime Differences: $D^0 \rightarrow K^+K^-$, $K_s^0\phi$, and $K\pi$. Comparison of decay rates can be made between the CP eigenstates, or to the mixed state $D^0 \rightarrow K\pi$.

2.1 Hadronic Decays of Tagged D^0 Mesons

In hadronic decays, it is possible to reach the final state which would come from mixing by doubly-Cabibbo-suppressed decay. Such doubly-Cabibbo-suppressed decays are expected at about the level of today's limits on mixing. Thus, the analyses must take these decays into account. The methods used involve a

maximum-likelihood fit to a sample of events which have the characteristic charge correlations for mixing. The fit function for the signal includes the signature for the D^0 decay (a Gaussian-function distribution for the effective mass of the D^0 decay products, $G_D(M)$), the signature for the tagging D^* decay (a Gaussian-function distribution in the mass difference in the D^* decay, $G_{D^*-D}(Q)$), and the separate proper-time distributions for probabilities coming from mixing, from the doubly-Cabibbo-suppressed mechanism, and from the interference of mixing and doubly-Cabibbo-suppressed amplitudes. The proper time of decays is needed to separate origins in mixing from double-Cabibbo-suppression. The backgrounds, $B(M, Q, t)$, are also parameterized in terms of the same variables as used for the signal. Expressions for the terms in the maximum-likelihood function are given in Eqns. 1 to 5.

$$N(M, Q, t) = G_D(M) * G_{D^*-D}(Q) * \epsilon(t)S(t) + B(M, Q, t) \quad (1)$$

Where, for the signal part:

$$S(t) = [N_{MIX} * f_{MIX}(t) + N_{DCSD} * f_{DCSD}(t) + N_{INT} * f_{INT}(t)] \quad (2)$$

$$f_{MIX}(t) = t^2 * e^{-\Gamma t} \quad (3)$$

$$f_{DCSD}(t) = e^{-\Gamma t} \quad (4)$$

$$f_{INT}(t) = t * e^{-\Gamma t} \quad (5)$$

and the detection efficiency, $\epsilon(t)$, may be a function of the proper time.

We are now entering the time when the interference term may provide the greatest sensitivity to mixing, since the square of the limit on the mixing amplitude is now smaller than the visible doubly-Cabibbo-suppressed rate. Of course, such sensitivity depends on the phase between the Cabibbo-favored and doubly-Cabibbo-suppressed amplitudes. Yesterday's background may be tomorrow's signal enhancer!

The recent mixing results are shown in Table 1. The earliest of these comes from the full data set of Fermilab's E791 charm hadroproduction experiment. ⁷⁾ These results are final, and published. Distributions are shown for the E791 hadronic-decay study ⁸⁾ in Fig. 1. The figure gives an indication of the kind of distributions which enter the maximum-likelihood fits using Eqns. 1 to 5. The ALEPH data comes from the full Z^0 data from 1991-1995 running at LEP, and have also been published. ⁹⁾ The CLEO II.V preliminary

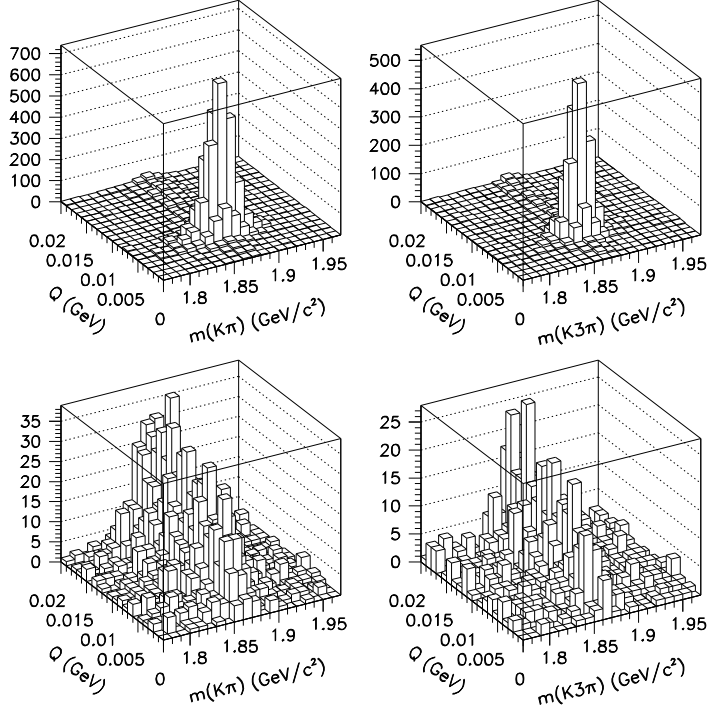


Figure 1: *The E791 signals used to establish a limit on charm mixing. Both $D^0 \rightarrow K\pi$ (left) and $D^0 \rightarrow K\pi\pi\pi$ (right) are shown. The Cabibbo-favored signals are shown in the top figures, the opposite sign correlations on the bottom.*

result, ¹⁰⁾ ¹¹⁾ ¹²⁾ which comes from the data shown in Fig. 2, is also from their full data set of $9fb^{-1}$. The first results from Fermilab's photoproduction experiment, FOCUS/E831, are expected soon, ¹³⁾

The CLEO result is the most constraining, at the level of 0.05 %, coming from the fact that the wrong-sign events (those characteristic of mixing and of doubly-Cabibbo-suppressed decays) appear at short proper decay-time. The short lifetime of these events strongly rejects large constructive interference between mixing and DCSD. As seen in Table 1, some earlier mixing analyses assumed no CP violation; and there are results quoted with the interference term arbitrarily set to zero. The more general fits, allowing the most general solution, typically result in looser quoted constraints on mixing. The excellent CLEO acceptance at short proper-lifetime relative to that at fixed-target ex-

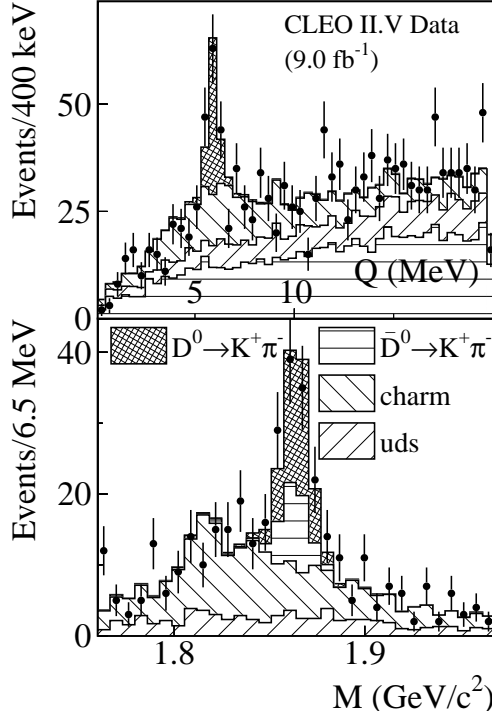


Figure 2: The CLEO wrong-sign signal used to establish their $D^0 \rightarrow K\pi$ limit on mixing. In the top plot, M is within 14MeV of the nominal D^0 mass, and for the bottom plot Q is within 500KeV of the nominal value. The signal and various backgrounds are indicated in the figure by hatching, with the data given by the points with error bars.

periments also makes the CLEO result less sensitive to the generality of the fit used.

2.2 Semileptonic Decays of D Mesons

Semileptonic decays have the advantage that there is no doubly-Cabibbo-suppressed decay to obscure a mixing interpretation. Tagging of the initial state is still required, of course. While the E791 results⁷⁾ are available and listed in Table 1, only the promise of the FOCUS/E831 data set is known.¹³⁾ They project a 90% CL upper limit of 0.1% after combining their electron and muon mode data, and assuming that "they observe precisely zero background-subtracted events in their wrong sign signal region."¹³⁾ We anxiously await

the result of their full data set.

2.3 Lifetime Differences Among Various CP Mixtures of Neutral D Mesons

Mixing can appear if there is either a difference in the masses of the CP eigenstates Δm or if there is a difference in the decay rates $\Delta\Gamma$ (Eqn. 6).

$$r_{MIX} = \frac{(\Delta m)^2}{2\Gamma^2} + \frac{(\Delta\Gamma)^2}{8\Gamma^2} = \frac{1}{2}(x^2 + y^2), \quad (6)$$

$$\Gamma = (\Gamma_1 + \Gamma_2)/2 \quad (7)$$

where Γ_1 is for CP-even states, Γ_2 for CP-odd states, and

$$\Delta\Gamma = \Gamma_1 - \Gamma_2. \quad (8)$$

Γ_1 applies to $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$ and Γ_2 applies to $D^0 \rightarrow K_s^0\phi$, $K_s^0\omega$, and $K_s^0\rho$. Γ applies to $D^0 \rightarrow K\pi$, if CP is conserved. And, then

$$\Delta\Gamma = 2(\Gamma_{KK} - \Gamma_{K\pi}) = 2(\Gamma_{K\pi} - \Gamma_{K\phi}) = \Gamma_{KK} - \Gamma_{KVector} \quad (9)$$

The E791 measurement ¹⁴⁾ gives

$$\Delta\Gamma = 2(\Gamma_{KK} - \Gamma_{K\pi}) = (0.04 \pm 0.14 \pm 0.05)ps^{-1} \quad (10)$$

This directly measured $\Delta\Gamma$ limit is more constraining than that which is obtained from Eqn. 6, the indirect limit from no mixing assuming Δm is zero. Results including the CP-odd decays are anticipated from CLEO and FOCUS.

2.4 What Models Are Tested in Charm Mixing?

As we have noted, typical Standard-Model predictions are many orders of magnitude smaller than the results in Table 1. However, there are many non-standard models which predict charm mixing at, or even above, the current limits. These models include those with light leptoquarks, SUSY particles, fourth-generation quarks, and Higgs particles. In each case, these objects occur in internal loops and their effects are virtual, if observable. And, in spite of calling such virtual particles light, their masses are still much above the mass reach of direct-production experiments, even at today's highest energy

Table 1: *Recent Results on Charm Mixing. Values for r_{MIX} , x , x' , y , and y' are given in %; values for $\Delta\Gamma$, in ps^{-1} . D_{tag}^o refers to D^o 's whose particle-antiparticle nature at birth is known (tagged). Confidence levels as are indicated explicitly when not at 90%. The CLEO result has been updated from what was presented at the workshop. ¹²⁾*

Decay Mode	Results (% , ps^{-1})	90% CL Limit	Exp.
$D_{tag}^o \rightarrow K\pi$		$r_{MIX} < 0.92$ (95% CL)	ALEPH No CP V. No Interf.
$D_{tag}^o \rightarrow K\pi\pi\pi$	$r_{MIX} = 0.21 \pm 0.09 \pm 0.02$	$r_{MIX} < 0.36$	E791 No CP V. No Interf.
$D_{tag}^o \rightarrow K\pi$	$x' = 0.0 \pm 1.5 \pm 0.2$ $y' = -2.5^{+1.5}_{-1.4} \pm 0.3$	$r_{MIX} < 0.05$ (95% CL)	CLEO II.V
$D_{tag}^o \rightarrow K\pi$ and $D_{tag}^o \rightarrow K\pi\pi\pi$	$r_{MIX} = 0.18^{+0.43}_{-0.39} \pm 0.17$ $r_{MIX} = 0.70^{+0.58}_{-0.53} \pm 0.18$	$r_{MIX} < 0.94$ $r_{MIX} < 1.31$	E791 $\overline{D}^o \rightarrow D^o$ E791 $D^o \rightarrow \overline{D}^o$
$D_{tag}^o \rightarrow K\mu\nu$ $D_{tag}^o \rightarrow Ke\nu$	$r_{MIX} = 0.06^{+0.44}_{-0.40}$ $r_{MIX} = 0.16^{+0.42}_{-0.37}$	$r_{MIX} < 0.50$	E791
$D^o \rightarrow KK$	$\Delta\Gamma = 0.04 \pm 0.14 \pm 0.05$ $y = 0.8^{+2.9}_{-1.0}$	$-0.20 < \Delta\Gamma$ $\Delta\Gamma < 0.28$ $-2.4 < y < 5.6$	E791 No CP V.

machines. Harry Nelson has compiled over thirty Standard-Model and non-Standard-Model predictions, ³⁾ and promised to keep his compilation updated. What he shows is the largest mixing rate for each model assuming "standard" couplings. In fact, a more detailed summary cannot be presented in a single parameter such as the rate, since each prediction depends not only on the mass of the virtual particle involved, but also on its couplings to the charm and other quarks of the final state. Examples of two-dimensional exclusion regions are given for representative models by Gustavo Burdman ⁴⁾ and Joanne Hewett. ⁵⁾ What we see are limits on otherwise allowed parameters, but more or less at the extremes of what we might otherwise expect. That is, charm measurements do limit the parameter space of allowed particles beyond the Standard Model. However, we are just getting into the most interesting regions now. The future

could be much more exciting.

3 CP Violation

There are four types of searches for CP violation: three for asymmetries in the decay rates of charm particles and antiparticles and one for differences in density distributions in Dalitz plots for decaying particles and antiparticles. The decay-rate asymmetries may be due to: (1) particle-antiparticle mixing, (2) direct CP violation in particle and antiparticle decays to identical final states, and (3) direct CP violation in decays to different final states (i.e., opposite charges). The first two of these occur only for neutral meson decays. The second is only possible for Cabibbo-suppressed decays. The third is pursued in charged-meson decay.

The ideal situation for observing CP violation occurs when there are two routes to a given final state, the amplitudes describing the routes have a significant relative phase, and there is a significant difference in the strong phases of the final-states depending on the route. In addition, it is best if the amplitudes for the two routes have comparable magnitude. We can see these features if we write the generic, total amplitude for decay via two mechanisms as

$$A = A_1 e^{i\delta_1} + A_2 e^{i\delta_2} \quad (11)$$

where the A_i are the (complex) weak-decay amplitudes and the δ_i are the relevant strong-interaction phases. The CP conjugate amplitude is

$$\bar{A} = A_1^* e^{i\delta_1} + A_2^* e^{i\delta_2} \quad (12)$$

Then, the CP violation is observed as a non-zero asymmetry calculated from the decay rates of the particle and antiparticle:

$$A = \frac{2 \operatorname{Im} A_1 A_2^* \sin(\delta_1 - \delta_2)}{|A_1|^2 + |A_2|^2 + 2 \operatorname{Re} A_1 A_2^* \cos(\delta_1 - \delta_2)} \quad (13)$$

Ideally, i.e., for large measurable asymmetries, one would like $|A_1|$ and $|A_2|$ to be comparable in size, and both the phases of the weak amplitudes A_i and of the strong phases δ_i should be quite different.

3.1 Rate Asymmetries

For neutral D -mesons, CP violation may occur via particle-antiparticle mixing and via direct CP violation. In mixing, the two amplitudes involved are those relating to the particle and antiparticle decays to the final state. For direct CP violation, the two amplitudes come from different mechanisms for the meson to decay directly to the given final state. Two such amplitudes are those for the spectator and penguin mechanisms.

Charged D -mesons can have only direct CP violation. As an example of direct CP violation, consider the decay $D^+ \rightarrow K^*(892)K$. In this case, the spectator amplitude involves the product of CKM matrix elements $V_{cs}^*V_{us}$, while the penguin amplitude involves $V_{cb}^*V_{ub}$. Thus, there are two weak amplitudes with a phase difference given by the CKM matrix phases. In addition, the spectator process involves both isospin 1/2 and 3/2 amplitudes. The penguin process is pure isospin 1/2. The strong phases of these isospin amplitudes can have very different values due to final state interactions in kinematic regions with nearby resonances. In fact, Alain LeYaouanc has predicted A_{CP} to be $\sim 10^{-3}$ ¹⁸⁾ and Franco Buccella has predicted $\sim (1.4 - 2.8) \times 10^{-3}$. ¹⁹⁾ In general, final-state interactions (rescattering effects) are important for charm. For example,

$$B(D^0 \rightarrow K^0 K^0)/B(D^0 \rightarrow K^+ K^-) = 0.24 \pm 0.09 \quad (14)$$

where a ratio more nearly unity is expected if only phase-space differences are considered.

As an example of the experimental method, consider the effective mass plots from FOCUS for the Cabibbo-suppressed decays of the charged and neutral D mesons shown in Fig. 3. The peak on the left of each figure is due to the relevant D decay. There is an immediate observation that the numbers of mesons and antimesons are unequal in each case. However, one must first take account of the differences in production rates. This is done by taking the asymmetry of ratios; i.e., of each signal normalized to its observed Cabibbo-favored decay. Table 2 lists the recent results on CP violation searches. The results come, again, from E791 ¹⁵⁾ ¹⁶⁾ and from FOCUS. ¹⁷⁾

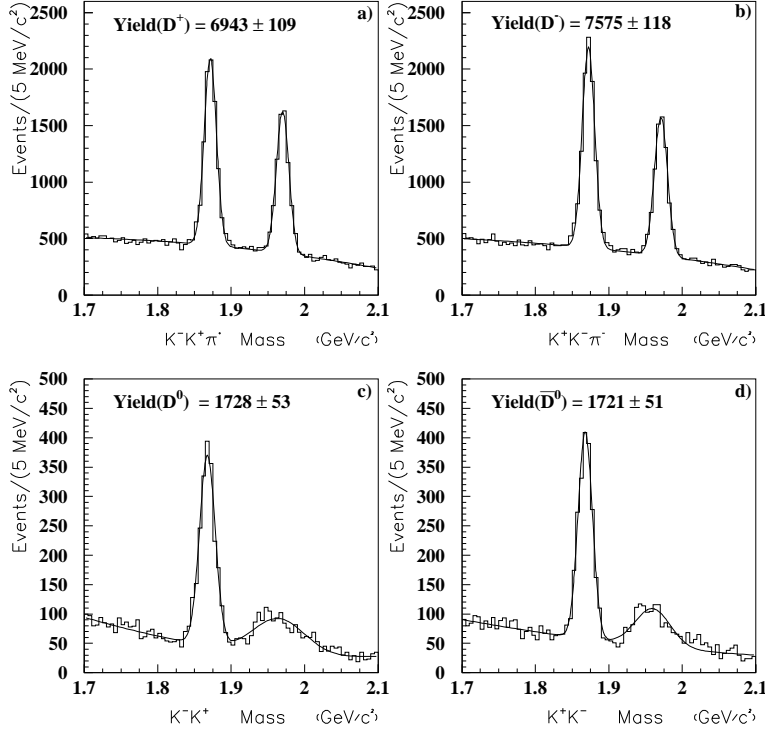


Figure 3: *Invariant mass, from the total FOCUS data sample, for a) $D^+ \rightarrow K^- K^+ \pi^+$, b) $D^- \rightarrow K^- K^+ \pi^-$, c) $D^0 \rightarrow K^- K^+$, and $\bar{D}^0 \rightarrow K^- K^+$.*

3.2 Differences in Dalitz Plots of Particle and Antiparticle Decays

In the literature, there are no results quoted so far for differences in Dalitz plots as a search for CP violation. In general, experimenters use such comparisons to look for instrumental asymmetries which must be found and removed – if they look at all. In the case of charm, typically, when there is more than a single Standard Model contribution to a decay channel, there are no phase differences expected in the amplitudes for particle and antiparticle. In order to be seen, any new-physics contribution should contribute to one of the possible amplitudes so that there is a net phase difference available for the interference term in the decay rate. It is instructive to look at the Dalitz plot (Fig. 4) for E791 data on the decay $D^+ \rightarrow K^- \pi^+ \pi^+$. This Dalitz plot shows very clearly what interference with a coherent phase difference can do in a Dalitz plot. There is a large K^* contribution and a much broader contribution evident

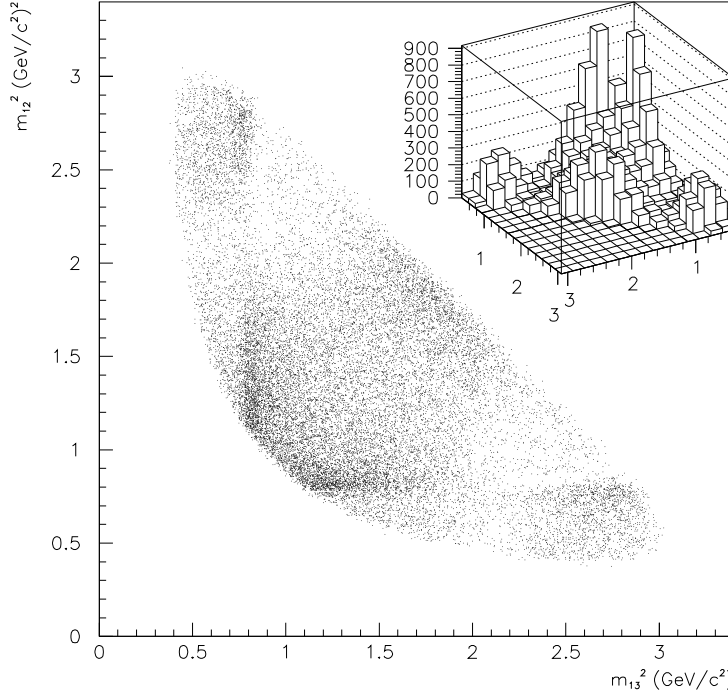


Figure 4: *Dalitz-plot distribution of events for $D^+ \rightarrow K^- \pi^+ \pi^+$ from Experiment E791.*

in the plot. Note the change from constructive to destructive interference as one moves from one side of the K^* mass squared to the other. If there were a difference in this pattern between D^+ and D^- decays, we would have evidence of CP violation. In fact, the place to look would be in Cabibbo-suppressed modes where any CP-violation signal is more likely. Although the available statistical precision of the data does not allow such visual clarity as that in Fig. 4, we may hope to achieve this level with future charm data.

3.3 What Models Are Tested in Searches for CP Violation?

The typical 90% confidence level limits shown in Table 2 are at the 10^{-1} level. As noted, the Standard-Model asymmetry predictions from higher order and long range processes are at the 10^{-3} level. Thus, there is a so-called "window of opportunity" of two orders of magnitude in which non-Standard-Model effects

Table 2: *Recent Results on CP Violation.* D_{tag}^o refers to D^o 's whose particle-antiparticle nature at birth is known (tagged). The FOCUS results are preliminary, and their reported errors are just the statistical errors.

Decay Mode	Result (%)	90%CLLimit(%)	Experiment
$D^+ \rightarrow K\bar{K}\pi$	-1.2 ± 1.1 -1.4 ± 2.9	$-6.2 < A_{CP} < 3.4$	FOCUS E791
$D^+ \rightarrow \phi\pi$	-2.8 ± 3.6	$-8.7 < A_{CP} < 3.1$	E791
$D^+ \rightarrow K^*(892)K$	-1.0 ± 5.0	$-9.2 < A_{CP} < 7.2$	E791
$D^+ \rightarrow \pi\pi\pi$	-1.7 ± 4.2	$-8.6 < A_{CP} < 5.2$	E791
$D_{tag}^o \rightarrow KK$	0.0 ± 2.2 $-1.0 \pm 4.9 \pm 1.2$	$-9.3 < A_{CP} < 7.3$	FOCUS E791
$D_{tag}^o \rightarrow \pi\pi$	$-4.9 \pm 7.8 \pm 3.0$	$-18.6 < A_{CP} < 8.8$	E791
$D_{tag}^o \rightarrow K\pi\pi\pi$	$1.8 \pm 2.3 \pm 0.2$	$-5.5 < A_{CP} < 1.9$	E791

might be observed. Such effects could be due to processes in models with SUSY particles, left-right symmetric particles, or extra Higgs particles. ²⁰⁾

4 Overview of What's Been Achieved

In order to understand the increased sensitivity achieved so far, we need to look at the numbers of observed events in each of a variety of physics analyses. Table 3 gives the numbers for the latest round of experiments on mixing and CP violation. Since some of the data sets are not fully analyzed, we should extrapolate each experiment's numbers to the size of its full recorded set. At the same time, it is best to make comparisons in an equivalent way, independent of the varied background level present in each experiment. We do this in each case by taking the square of the ratio of the number of events divided by the quoted statistical error in that number. Such figures-of-merit are presented in Table 4.

From the numbers in Table 4, it appears that CLEO and FOCUS will have the best results from existing data sets for most topics. Between the two experiments, the results will improve over hadroproduction experiment E791 by factors of three for hadronic modes and ten for semileptonic modes. We may expect the errors to scale as the inverse of the square root of the numbers of events. Systematic errors will need to be reduced accordingly, a task which is easier at e^+e^- machines where the signals often appear with less background.

Table 3: *Numbers of Observed Events by Analysis. CLEO results in parentheses are from only 5.6fb^{-1} of 9.1fb^{-1} collected. The ALEPH collaboration has recently reported a result based on $1,039 \pm 33 D_{tag}^0 \rightarrow K\pi$ events, not listed in the table to save space. The CLEO CP-violation result has been added since the workshop.* ¹²⁾

Physics Topic	Decay Mode	E791	CLEO II.V	FOCUS
Mixing	$D_{tag}^0 \rightarrow K\pi$ $D_{tag}^0 \rightarrow K\pi\pi\pi$	$5,643 \pm 77$ $3,469 \pm 60$	$16,126 \pm 127$	
Mixing	$D_{tag}^0 \rightarrow K\mu\nu$ $D_{tag}^0 \rightarrow Ke\nu$	$1,267 \pm 44$ $1,237 \pm 45$		$16,522 \pm 200$ (92%)
$\Delta\Gamma$	$D^0 \rightarrow KK$ $D^0 \rightarrow K\pi$ $D^0 \rightarrow K_s^0\phi$	$3,200 \pm 57$ $35,400 \pm 206$	$(1,300 \pm 40)$ $(19,000 \pm 140)$ $(3,000 \pm 60)$	$99,800 \pm 340$
CP Vio.	$D^+ \rightarrow KK\pi$ $D^+ \rightarrow \phi\pi$ $D^+ \rightarrow K^*K^+$ $D^+ \rightarrow \pi\pi\pi$ $D^+ \rightarrow K\pi\pi$	$2,296 \pm 65$ $1,072 \pm 38$ 530 ± 26 $1,548 \pm 64$ $51,479 \pm 272$		$14,518 \pm 161$ $146,497 \pm 426$
CP Vio.	$D_{tag}^0 \rightarrow KK$ $D_{tag}^0 \rightarrow \pi\pi$ $D_{tag}^0 \rightarrow K\pi\pi\pi$ $D_{tag}^0 \rightarrow K\pi$	609 ± 29 343 ± 25 $3,409 \pm 62$ $13,273 \pm 129$	$3,023 \pm 66$ $13,527 \pm 116$	$3,449 \pm 74$ $39,206 \pm 211$

When the systematic uncertainties can be controlled with the increased amount of data, the physics reach will improve by factors of the square root of three to the square root of ten. For future data sets, physics reach will also scale like the square root of these reduced numbers of reconstructed decays.

5 Expectations for the Future

We have seen excellent signal to (well understood) backgrounds in today's charm decay experiments. This has led to real improvements in sensitivity to new physics. The progress has been the result of precision reconstruction of production and decay vertices, excellent kinematic resolution, and increasingly large data samples. Some of this has come from dedicated charm experiments; other progress is the byproduct of B-motivated experiments. Since we may

Table 4: *Numbers of Equivalent Pure Decays Observed by Analysis (scaled to full data sets where needed). The CLEO CP-violation result has been added since the workshop. ¹²⁾*

Physics Topic	Decay Mode	ALEPH	E791	CLEO II.V	FOCUS
Mixing	$D_{tag}^o \rightarrow K\pi$ $D_{tag}^o \rightarrow K\pi\pi\pi$	1000	5,400 3,300	16,000	
Mixing	$D_{tag}^o \rightarrow K\mu\nu$ $D_{tag}^o \rightarrow Ke\nu$		750 760		7,400
$\Delta\Gamma$	$D^o \rightarrow KK$ $D^o \rightarrow K\pi$ $D^o \rightarrow K_s^o\phi$		3,150 29,500	1,700 30,000 4,100	86,000
CP Vio.	$D^+ \rightarrow KK\pi$ $D^+ \rightarrow \phi\pi$ $D^+ \rightarrow K^*(892)K^+$ $D^+ \rightarrow \pi\pi\pi$ $D^+ \rightarrow K\pi\pi$		1,250 800 420 590 36,000		8,100 120,000
CP Vio.	$D_{tag}^o \rightarrow KK$ $D_{tag}^o \rightarrow \pi\pi$ $D_{tag}^o \rightarrow K\pi\pi\pi$ $D_{tag}^o \rightarrow K\pi$		440 190 3,000 10,500	2,100 13,500	2,200 35,000

have seen the last of dedicated charm experiments [Can we hope still for a t-charm Factory?], we need to understand what may be expected from future B-motivated experiments.

There is the potential for 10^7 reconstructed charm decays from B factories (and COMPASS); also the potential for 10^{8-9} from BTeV (and LHC-b?). Even though hadron environments may be harder, the production rate, coupled to capable detectors, can win in the end. This has been shown by E791. However, triggers will have to allow/encourage charm data to be taken! As it is, charm events may be the worst enemy of B-experiment triggers. Often, B experiments actively try to minimize the charm events recorded.

6 Summary and Conclusions

Charm experiments have reached the level of 10^6 reconstructed meson decays. FOCUS holds the record in this regard today. So far, there is no evidence for either mixing or CP violation in the charm sector.

The march toward increasing numbers of well-reconstructed decays with well-understood backgrounds has led to decades of increased sensitivity over the last years. There is hope for continued progress in this direction. However, this hope depends mostly on results coming as a side benefit from the major B efforts coming on line, especially those whose on-line event selection allows charm data to be taken.

The mass reach for new physics sources via virtual processes in charm decay greatly exceeds what can be directly produced now, or in the foreseeable future. Who knows, new physics could be just around a charmed corner.

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